Near-field optical imaging of plasmonic devices using heterodyne optical feedback on Er doped DFB fiber laser

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Abstract : Near field Scanning Optical Microscopy using heterodyne optical feedback on Er-doped DFB fiber laser at λ=1.55µm is investigated for optical characterizations of plasmonic waveguides. The experimental results are compared with FDTD numerical models.
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Laser Feedback Interferometry (LFI) has been already investigated as an efficient tool for near-field optical imaging [1,2]. In this specific approach, the optical near-field collected by a micro tip on the top of the studied sample is frequency shifted before being re-injected in the single-frequency class B laser used to illuminate the device. Adjusting the frequency shift close to the relaxation oscillations of the laser leads to a strong amplification (up to +60dB) compared to a classical interferometric set-up [3]. In the case of Near field Scanning Optical Microscopy (NSOM), it allows amplitude and phase detection of the optical near field with quantum-noise limited signal-to-noise ratio. The technique is currently applied for characterizing plasmonic devices processed by e-beam lithography. Using the Kretschmann-Raether (KR) configuration [4], the incident light beam was efficiently coupled to a Surface Plasmon-Polariton (SPP) guided mode which propagates along the selected gold structure (figure 1). A single-frequency DFB Er-doped fiber laser emitting up to 8mW in single-frequency regime at λ=1550nm was selected as the laser source. Such fiber laser source is well-suited for LFI-SNOM measurement because of its intrinsic high sensitivity to heterodyne optical feedback and its direct coupling to single-mode telecom fiber. Moreover, near λ=1550nm, the SPP propagation length L_p along a single planar gold/air interface could exceed hundreds micrometers, which is a reasonably long-range for SPP. The optical feedback loop is all-fiberized with an optical circulator used simultaneously as a beam splitter and a re-combiner. The fiber micro tip is scanned above the studied plasmonic waveguide (scanned area up to 20x20µm^2 with 5nm resolution) at constant distance (typically few dozen nanometres) using shear-force based regulation technique [5]. The collected light is frequency shifted by a pair of fiber-pigtailed acousto-optics modulators (AOMs) before being re-injected into the laser via the circulator. The frequency shift is adjusted near the relaxation oscillation frequency of the laser (typically around 600-700 kHz). Finally, the dynamical perturbation is photo-detected on the rear output of the laser and further processed via lock-in amplifier.

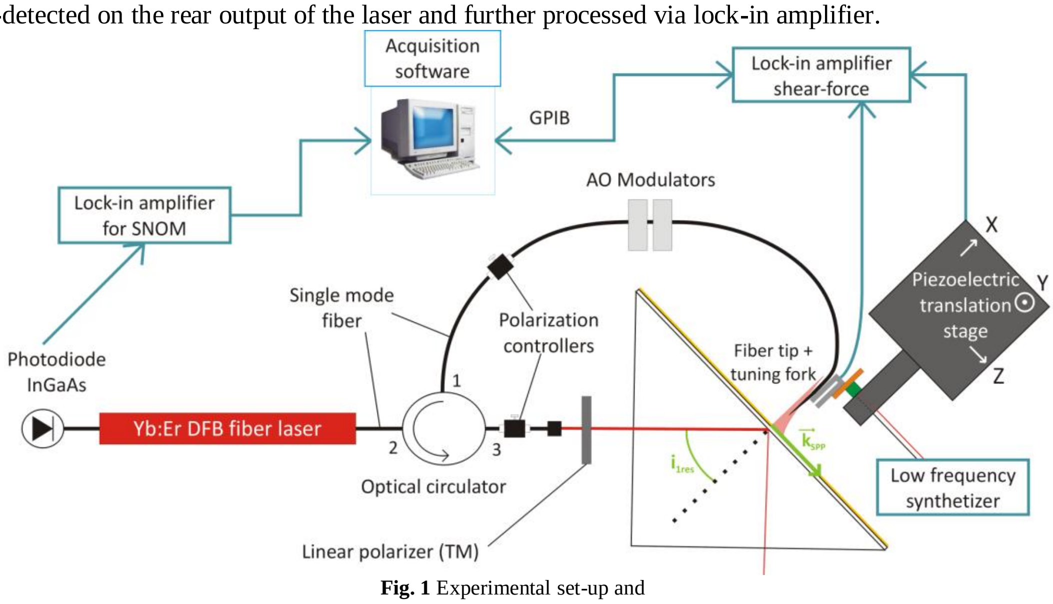

Fig. 1 Experimental set-up and

For example, figure 2 represents the amplitude of the detected field (top) and the surface topography (bottom) recorded along a w=10microns wide gold strip waveguide followed by a homogeneous gold area. Recorded near-field images were stitched together for increasing the scanning length along the waveguides.

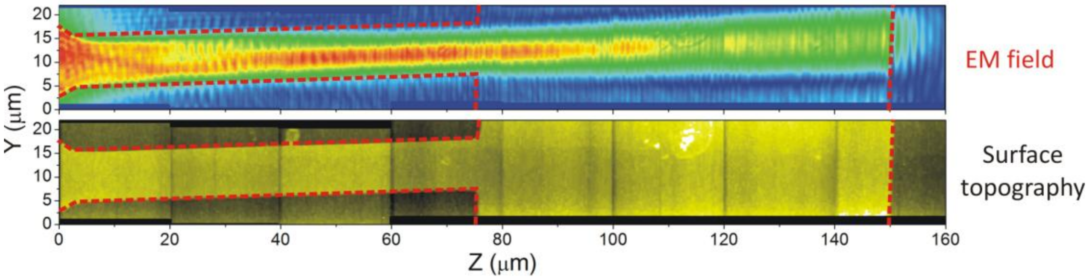

Fig. 2 Near-field Optical guided mode detected using LFI-SNOM technique applied on plasmonic gold devices.

2D and 3D Finite-Difference Time-Domain (FDTD) codes were developed for comparing the experimental results with numerical simulations. For example, the comparison of experimental and numerical profiles (figure 3). An adaptive mesh was specifically develop to take into account the strong dissymmetry at λ=1550nm between respectively the SPP penetration depths in gold metal (δ_{gold}=25nm) and in the air (δ_{air}=2.38µm). Visualization of the EM fields distributions of a quasi-TM guided mode on 5 microns wide and 30nm thick gold strip waveguide is illustrated in figure 4. Such numerical simulations allow determining the radiative losses respectively in the air cladding and in the glass substrate.

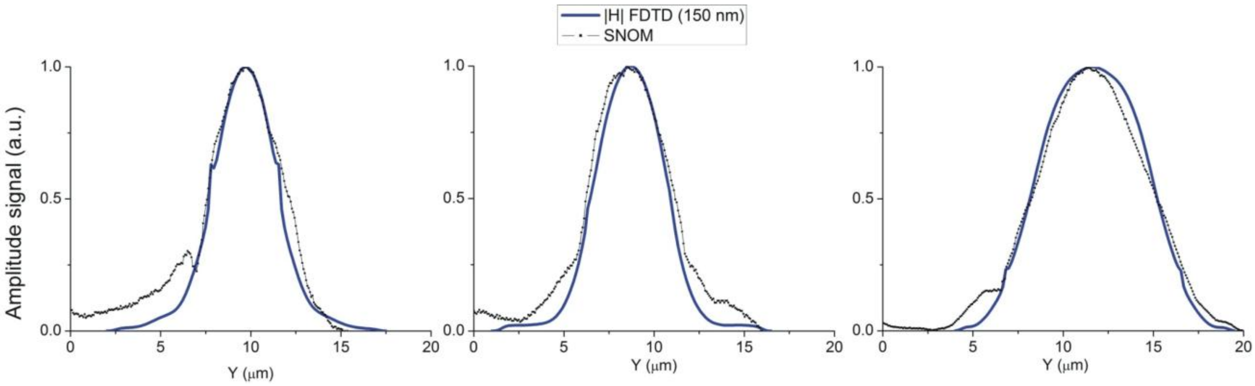

Fig. 3 Comparison of experimental and numerical profiles

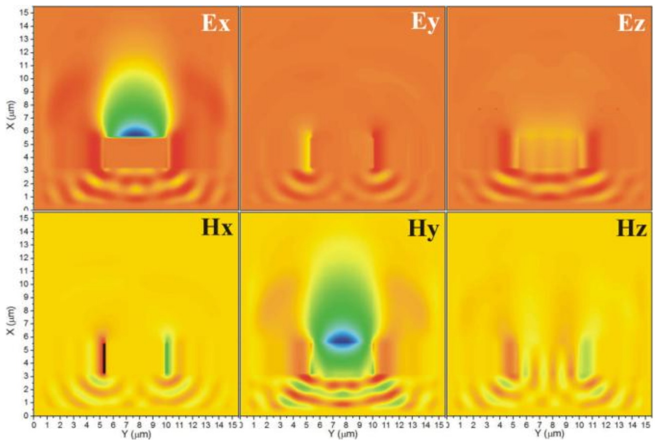

Fig.4 EM field of a quasi-TM mode on a 5 microns wide and 30nm thick gold strip

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